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SUSAN ROAF,
FERGUS NICOL
& WILLIAM FINLAYSON

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Susan Roaf, Fergus Nicol
& William Finlayson
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Optimising Comfort in Rural Villages of SW China

Adrian Pitts[1], Yun Gao[2] and Vinh Tien Le[3]

[1] Centre for Urban Design, Architecture and Sustainability, University of Huddersfield, UK. Email: a.pitts@hud.ac.uk
[2] Centre for Urban Design, Architecture and Sustainability, University of Huddersfield, UK. Email: y.gao@hud.ac.uk
[3] Centre for Urban Design, Architecture and Sustainability, University of Huddersfield, UK. Email: vinh.le@hud.ac.uk

Abstract: The rapid economic development of China has led to fast growth of its cities but also seen as increasingly important are its rural areas which were somewhat left behind in recent development; there are now many policies aiming to rebalance the variation. There are in addition particular circumstances impacting on redevelopment and design and construction which arises from the ethnic/nationality groupings to be found in SW China. One of the consequences of the rapid rural redevelopment is a focus more on acquisition of dwelling features found in urban apartments, rather than designing for the local climate and long-term sustainability. New dwellings are being constructed which whilst meeting the needs and requirements of the residents for more modern accommodation are not taking advantage of the potential to improve environmental design nor for occupant thermal comfort. Bioclimatic analysis and energy simulation software has been used to evaluate potential for improved dwelling design in the regions of interest. Results for five major city areas are presented and this demonstrates substantial opportunity to improve bioclimatic design and also to reduce discomfort. A research and practice network is helping draw stakeholders together to support and enhance future development and impact on choices being made so as to improve environmental outcomes.

Keywords: rural areas; dwellings; villages; comfort; China

1. Introduction

China has undergone a period of rapid urban and building development in the last 30 years; this development has been most obvious in the rapid expansion of its cities. Though China was originally a rural based economy with a largely rural based population, this situation has changed rapidly in recent times, and evidence to show the need to improve rural areas has influenced government policies. In addition, though it is less than previously, still approximately 570 million people live in what is classed as the countryside.

The urban development activities of recent decades have been undertaken with varying degrees of attention to sustainability issues. However, there have been many signs of a recognition of the need to address concerns of climate change and global warming, and of the need for efficient use of resources in construction and operation of the built environment [ref]. Whilst (as in the global west) economic sustainability takes precedence there is more attention now paid to issues of environmental, cultural and social sustainability.

In terms of overall development and prosperity, the lagging behind of rural areas began to give rise to concerns of inequality and the needs to consider promoting and supporting more specifically village redevelopment. The Chinese Government's 11th Five-Year plan of 2006 was the public start of this much needed redevelopment in rural areas (Government of the PRC, 2012). The subsequent speed of this revitalisation has meant that whilst many new dwellings have been constructed, the attention to sustainability has not been great and some opportunities for optimisation in the environmental design have not been taken.

Staff from the university of Huddersfield have been active in research into rural areas for a number of years: some of this has had a cultural theme; some other work has considered how dwellings could be designed with a greater emphasis on green and environmental issues (Pitts, 2016). In china as with almost all other countries a substantial amount of energy resource is needed to both construct buildings and also to maintain comfortable conditions inside buildings.

Many visits to rural areas of China have taken place allowing the research team to discover and evaluate different forms of construction with a specific emphasis in the Southwest quadrant of the country (Yunnan, Guizhou, Guangxi, Sichuan, and Chongqing) [Gao, 2016). This part of the country is somewhat removed from the more economically active East coast and also has a significant number of village areas that have been considered ripe for redevelopment.

This paper deals with a specific aspect of recent research, that is: evaluation of combinations of typical dwelling construction parameters in order to estimate the proportion of time that might be considered uncomfortable. This is being undertaken in order to provide both design professionals and also village leaders/residents with information to enable better choices about key building construction features that can be adjusted to improve comfort.

2. SW China

In SW China there are 4 provincial level areas (Yunnan, Guizhou, Guangxi and Sichuan) and one self –governing city (the only one not on the east Coast): Chongqing (Figure 1 illustrates the location). The total population is about 237 million (about 18% of the country's total). The region of SW China is culturally diverse with representation of many of China's 55 ethnic minorities (the population of China is largely of Han ethnic group – approximately 91.6% - with the remaining 55 minorities making up the other 8.4%). In the SW region populations from approximately 30 of those 55 other groups are to be found, and in some specific areas a particular nationality group will make up a significant fraction of the total. In some villages the situation can be even more important with almost all the local residents from a single group.

The impact of this is several-fold: there is a social and cultural closeness of the residents because of the family and clan-like structures; there are specific ethnic variations in traditional building design, clothing and language; there is tourist development potential to help support villages economically; and there is a drive from central government to help revitalise these areas.

The climate and topography of SW China are each rather variable: the are many changes in altitude which range overall from sea-level to over 4,000 metres and climate that ranges from hot and humid to cold. This means that solutions must be designed to meet the needs of specific locations and that a general regional or provincial approach is not satisfactory. In some areas where the altitude and other factors mean the temperatures are often below 0°C there is a need for heating whilst in others where temperatures regularly exceed 30°C with high humidity, there is a need for cooling. As a result it is important to understand how the building itself can be adjusted in each circumstance in order to improve comfort conditions and to reduce the needs for heating and cooling systems.

The region also has a number of areas of significant seismic activity which means new buildings have to be designed to meet appropriate building codes. Research involving the

Huddersfield team has also linked redesign/construction issues of traditional dwellings to seismic tests (Bai et al, 2019).

Figure 1: The Provinces of SW China (Pitts et al, 2019)

3. Rural Revitalisation

As mentioned previously, the issuing of the 11th Five Year plan in 2006 marked a clear start for rural revitalisation processes in China. Rural areas have both different citizenship statuses and also differences in land ownership. 'Villages' are also part of the government classification system in China and 'Administrative' villages are different to 'natural' villages. Natural villages can vary greatly in size though frequently in SW China they are relatively small affairs consisting of from a few tens to a few hundreds of inhabitants, and with a number of natural villages making up an Administrative village. The natural villages often consist mainly of inhabitants from one ethnic nationality and this can have impacts on the process of redevelopment (Gao, 2016), especially when there is also a tourist development aspect to the activity (Gao et al, 2014).

In specific areas guidance may also have been issued in support of redevelopment however this rarely considers climate-sensitive design and comfort (YHTCCD and YURP&DI, 2018a and 2018b). A further issue arises from the way in which redevelopment occurs, often involving construction companies taking the lead rather than designers, although village dwellers may also take the initiative themselves I certain projects. As a result, although there can be not insubstantial funding/subsidies available, there is more attention paid to maximising the size of the property and the inclusion of modern amenities rather than running costs such as for energy. This has the effect of bypassing consideration of more vernacular inspired designs or of a deeper consideration of those factors which can lead to use of bioclimatic techniques to achieve comfort/reduce discomfort. It also bypasses the craft skills and knowledge that might exist in a local area that could be used, and which would enhance economic and cultural sustainability.

Figure 2: Dwelling of traditional construction, Manzhang village, Yunnan

Figure 3: Dwelling of modern construction, Manzhang village, Yunnan

The outcome of this process can lead to the replacement of traditional, but old style dwellings, which lack modern features which local in habitants associated with a modern urban lifestyle, with a modern alternative constructed from concrete blocks walls and tiled roofs. Many bioclimatic design options that could address comfort requirements more ‘naturally’ are never considered. The contrasting ‘before’ and ‘after’ designs can be seen in examples from the same village shown in Figures 2 and 3.

4. Research Investigations

As part of a broader project, a range of investigations into aspects of sustainable development in rural villages in China has been undertaken. More than a dozen extended visits to villages in provinces of Southwest China occurred (sometimes more than once to the same village).
Most of these visits included meetings with village leaders as well as examination of the planning of the village and of individual dwellings. Discussion indicated many opportunities to introduce climate sensitive design into the processes of rural development but that lack of awareness or confidence in using such options also existed. As a result some opportunities to improve thermal comfort are not taken thus increasing energy use and soring up problems for the future with warming climates.

Leading on from the village visits was the establishment of a research group: *The Sustainable and Creative Villages Research Network – SW China*; this was funded by the Arts and Humanities Research Council (AHRC). Additional funding arose from participants in the network who were willing to fund attendance by their staff at a number of symposia held over a two-year period and also in providing facilities and support for the hosting of these events.

Several online dissemination and discussion groups were also set-up to facilitate communication about the topic and this proved to be a good way to encourage collaboration between subgroups within the network, total membership of which stands at over 50 at the time of writing. A further value from this process was the support for stakeholders to increase their levels of confidence in applying climate sensitive and bioclimatic design strategies. Over a period of three years a substantial amount of research investigation and analysis took place with involvement of local partners and this resulted in a number of outputs.

The impacts arising from these activities have been felt in several areas: firstly impacts on the design approaches and factors considered by professionals in practice (planning and architecture); second encouragement for multiple university/research organisations to collaborate; and thirdly impacts on the teaching curriculum with inter-institutional projects undertaken in the field (i.e. attached to villages). The work has also been showcased at recent international exhibition/conferences: the 4th ASEAN Architecture Art Forum held in Nanning, China and the 4th CSCEC Cup Western ‘5+2’ Biennale Exhibition of Environmental Art Design held in Kunming, both during November 2019.

These dissemination and impact features have proved to be very important and in order to provide valuable additional resources, further research was undertaken in SW China to examine potential to address comfort/discomfort issues. The evolution of these topics is discussed in the next section.

5. Energy and comfort

Arising from the investigations carried out within villages it seemed clear to the research team that whilst there was some understanding amongst stakeholders that alternative green and climate sensitive design options existed, that there was no clear mechanism for developing suitable solutions. Even professionals (planners and architects) lacked a clear understanding of what technologies and techniques existed and how to choose and design their integration into construction. The authors suggested that bioclimatic design techniques that are in common use elsewhere could be considered and that a simplified tool for assessing potential could be utilised. There was also a lack of understanding of different approaches to defining and assessing thermal comfort and whilst the PMV approach of Fanger (1970) was recognised, there was less understanding of adaptive approach such as shown in Nicol and Humphreys (2002) and Nicol (2011).

In order to address bioclimatic design issues, the authors identified the Climate Consultant software (UCLA, 2019) as providing the option with best combination of clarity and ease of use that was freely available. They also found a significant set of data records for climate existed for China in which 46 different locations in SW China could be identified.

The list of possible design techniques is provided in Table 1 below. The means to assess the potential for design benefit from these techniques was through the Climate Consultant software available from UCLA [ref]. The software produces outputs in a number of formats and for the purposes of this paper it was used to consider 5 major city areas in SW China for which climate data had been obtained through the EnergyPlus (EnergyPlus, 2019a) online link to weather files compiled by the China Meteorological Bureau (2015).

Of the list of techniques shown, about half can be considered to be 'passive' (that is requiring little or no external energy or sophisticated control system to function), and about half 'active' (those which do require additional energy and controls).

Table 1. Climate Sensitive Design Techniques in Climate Consultant Software

1	Basic design for comfort
2	Sun shading of windows
3	High thermal mass
4	High thermal mass night flushed (ventilated)
5	Direct evaporative cooling
6	Two-stage evaporative cooling
7	Natural ventilation cooling
8	Fan-forced ventilation cooling
9	Internal heat gain
10	Passive solar direct gain low mass
11	Passive solar direct gain high mass
12	Wind protection of outdoor space
13	Humidification only
14	Dehumidification only
15	Cooling with dehumidification if needed
16	Heating with humidification if needed

In addition to these differentiations it is also possible within the software to select calculation of comfort hours according to different comfort models. Two were chosen for this study: the 'ASHRAE Standard 55 and current Handbook of Fundamentals' model and the 'Adaptive Comfort Model in ASHRAE Standard 55 2010'. These produce different results because of the adaptive aspect of the second model. The data outputs are summarised in Table 2 for the five city regions: Chongqing; Nanning; Guiyang; Chengdu; and Kunming. In addition screen captures were collected of the resulting outputs using standard input conditions for the five locations showing the comfort potential zones on a psychrometric chart. These are shown in Figures 4- 8.

It was clear from these analyses that there was considerable opportunity to improve internal environmental conditions by making use of the design techniques; it was further noted that even if only 'passive' techniques were used, that there was a considerable benefit to be derived – up to 74% for one of the locations considered. Since it was the intention of the overall research programme to offer opportunities for design variation in a form that could be used by stakeholders, it was decide to pursue the investigation further. In order to do this a more sophisticated piece of software was selected EnergyPlus (2019b).

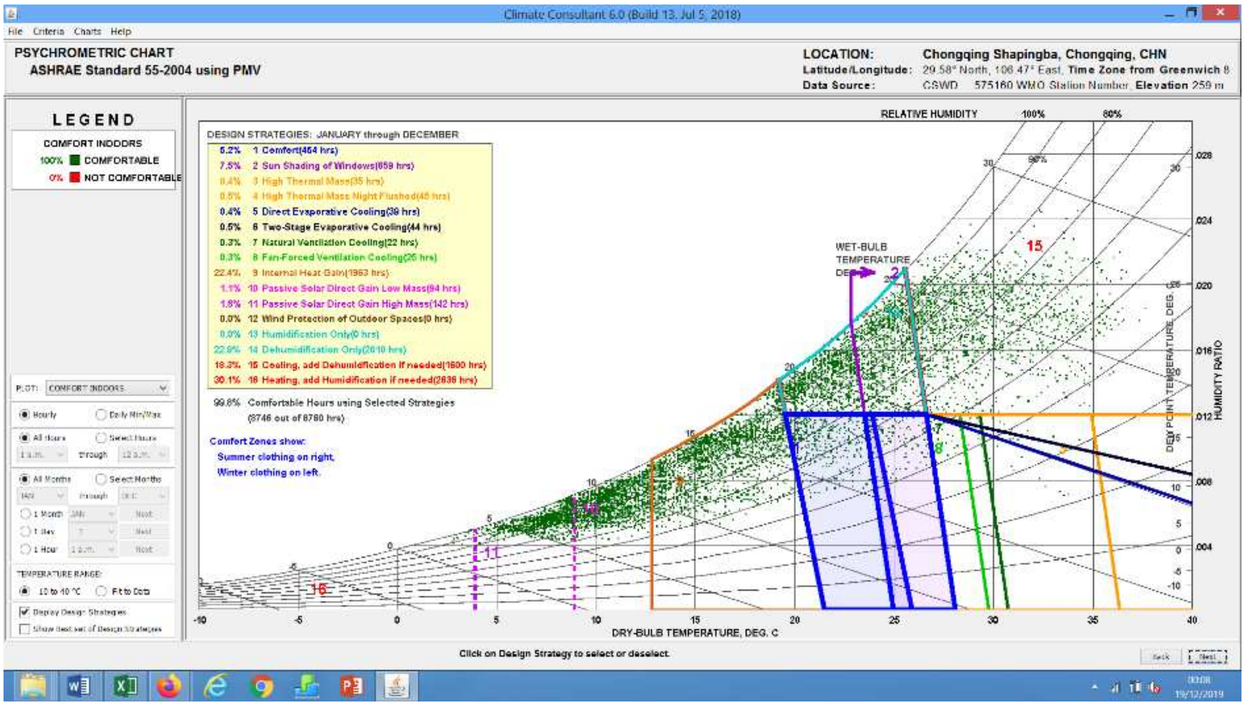

Figure 4: Design Strategies shown on Psychrometric Chart for Chongqing

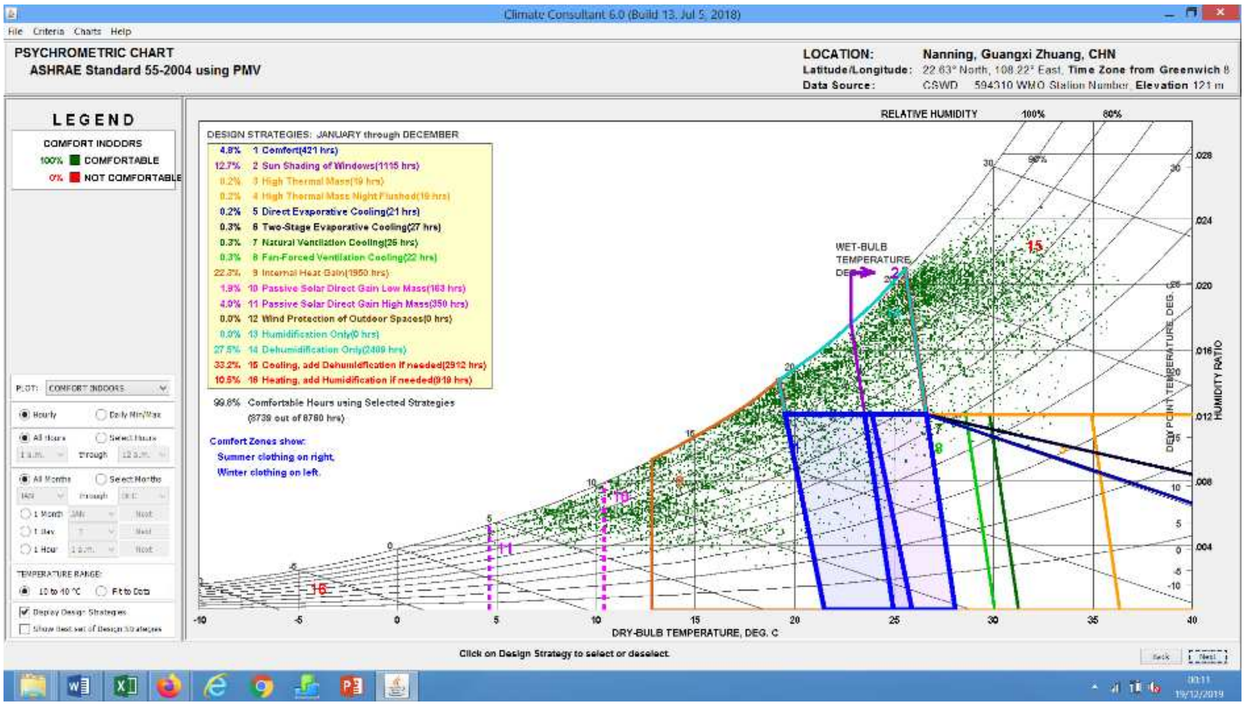

Figure 5: Design Strategies shown on Psychrometric Chart for Nanning, Guangxi

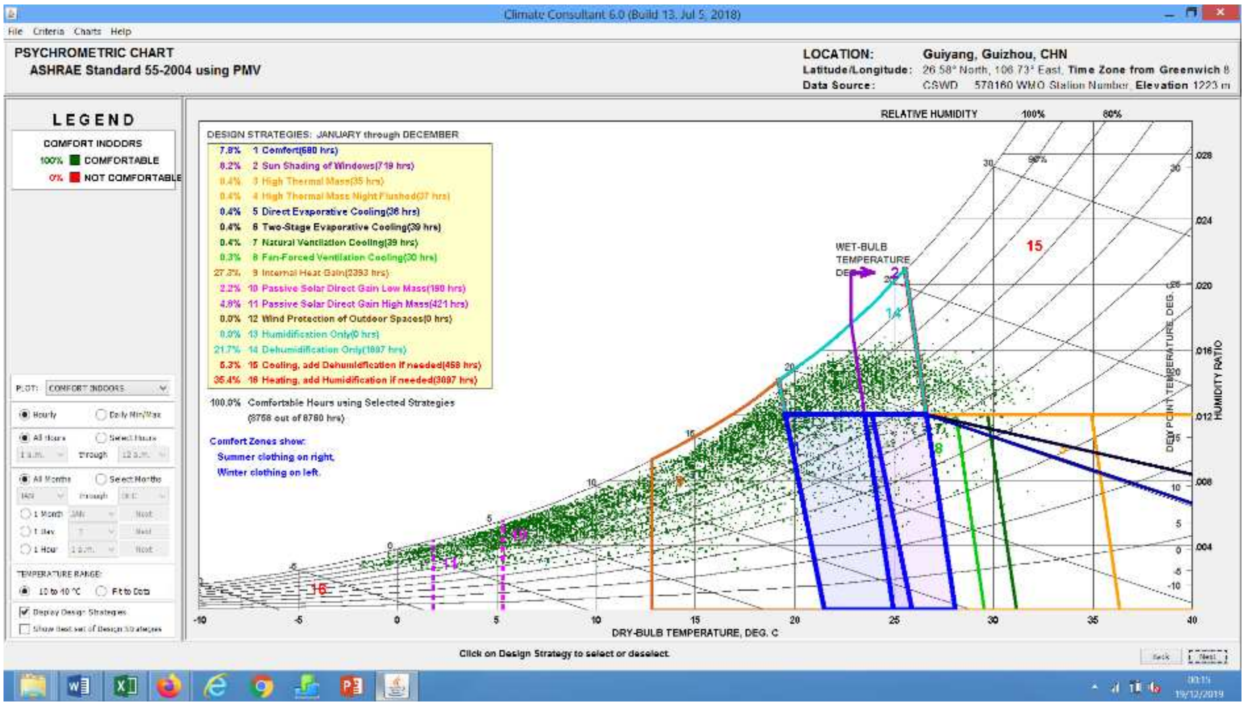

Figure 6: Design Strategies shown on Psychrometric Chart for Guiyang, Guizhou

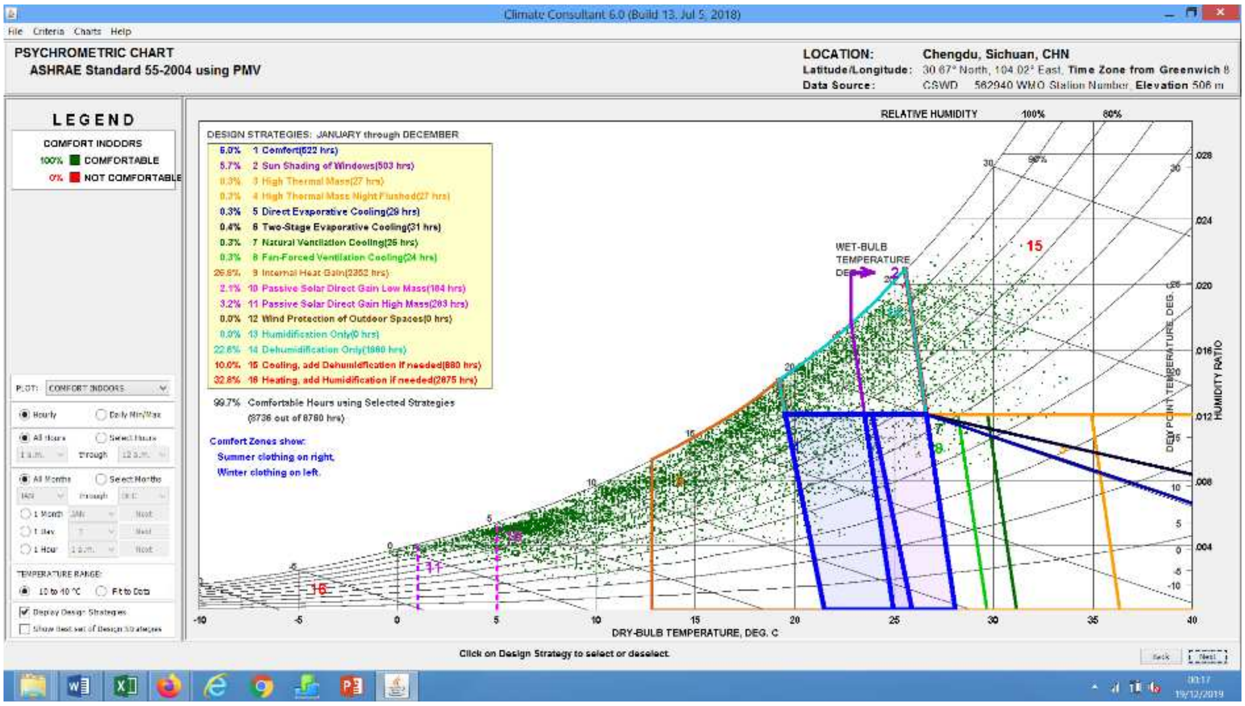

Figure 7: Design Strategies shown on Psychrometric Chart for Chengdu, Sichuan

EnergyPlus allows the modelling of internal conditions through use of a simulation technique. Required input data includes all thermal property and usage details for a building. A simple standard dwelling was chosen to be used together with parametric variations of the main features of design: wall construction; window area; air infiltration; orientation of the main façade; and also consideration of differences between upper and lower floor. The information box in the appendix indicates the range of variations considered; altogether these result in 216 simulations being carried out for each location.

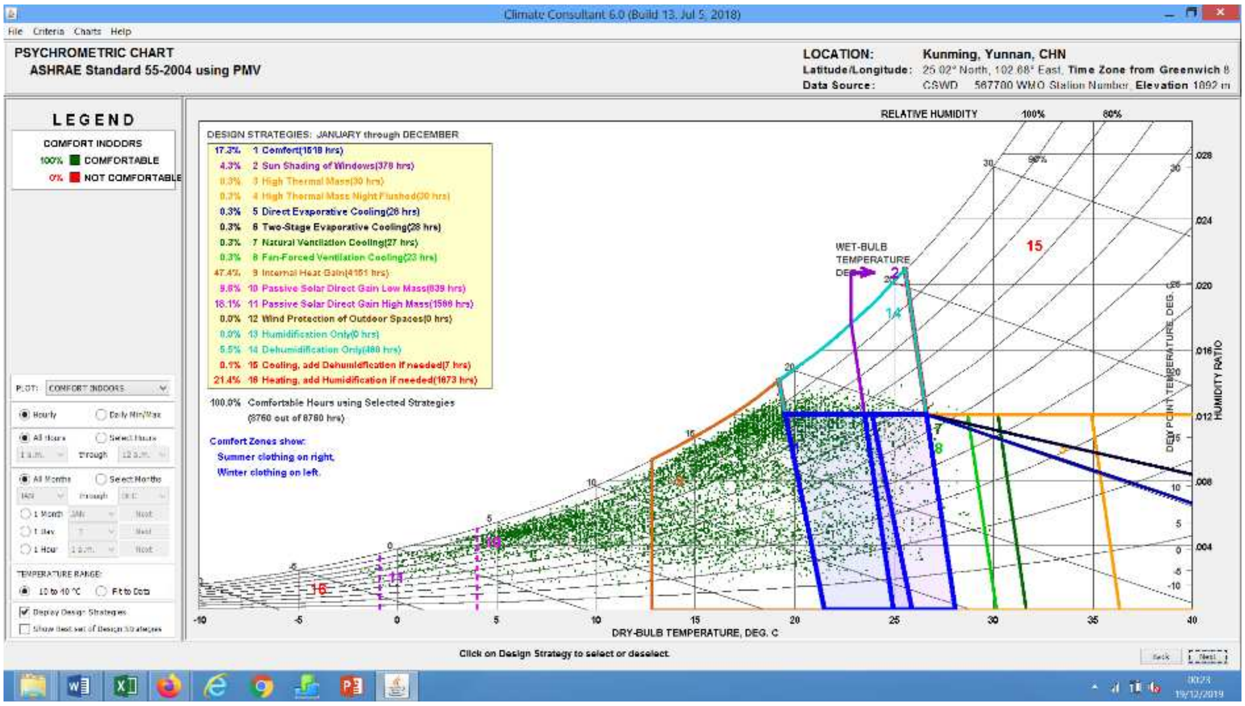

Figure 8: Design Strategies shown on Psychrometric Chart for Kunming, Yunnan

Following this process which generated very large datasets of values of internal conditions for every hour of the year for 216 simulation variations, analysis of outcomes was undertaken with reference to the predicted mean vote conditions. The variation from comfort was determined for every hour and then summed according to two different variabilities from neural. The acceptable variation from PMV of 0 is addressed in comfort standards with options to ±0.7, however in a previous study by one of the authors (Pitts and Bin Saleh, 2007) a case was made for extending the boundary for adaptable comfort to PMV ±1.0 and this was the criteria chosen. The reasoning for this came from the apparent acceptance of a wider range of conditions from local in habitants and particularly for inhabitants who had experience of very 'leaky' ethnic type dwellings. At this stage the comparison was undertaken for speculative reasons in order to examine the potential impact; further studies into this aspect are being undertaken but not reported here.

6. Results

As already stated Table 2 shows the variations in additional comfort hours (expressed as a percentage) that is generated by use of each technique using two comfort models. The total potential improvement is always less than the sum of the contributing techniques because in each case the adoption of one methods reduces the maximum benefits that can be accrued by use of another. Nevertheless, substantial improvements are demonstrated suggesting value in disseminating information to stakeholders and in particular to those in a position to influence design and construction decision making.

Tables 3 to 7 at the end of the paper provide comparative results from the EnergyPlus simulations for the five city region locations. The tables show the discomfort hours resulting if using an extended range of comfort prediction of PMV ±1.0.

6.1 Design evaluations:

Wall construction and thermal insulation

The results show that in many circumstances the use of thermal insulation in the lightweight wall constructions can produce some benefits. Since thermal insulation is not frequently used in building construction in Southwest China at the present time, this is something which designers might consider for the future. Benefits come not just from reducing heat loss in cooler periods but also from reducing heat gains in some warmer periods.

Air flow and ventilation

In many but not all situations there are benefits from controlling air flow in the building; more airtight constructions often performing better than leaky alternatives.

Window/glazing area and orientation

Variations in performance associated with changes to the glazing area are quite complicated to interpret in any general way and require the user to examine variations in conjunction with consideration of main orientation. This is not to say the variation is inconsequential, but rather it needs intelligent interpretation related to the actual site and climate.

Ground or first floor

There are differences in performance between ground floor areas and first floor areas. This can have significant implications for overall comfort – for instance in certain climates it may be better to have main living spaces on the ground floor and in other climates better to make more use of the upper first floor. It might also be useful to consider that at different times of the year the ground floor may be preferable whilst the first floor may be preferred at other times. The level of data analysis in the appendix does not allow that level of analysis at the moment though it can be considered at a later date.

6.2 Site location opportunities

The summary below indicates the general site location recommendations for each of the city regions.

Shapingba, Chongqing: average discomfort hours 75.8% (range 71.3%-78.9%). Lightweight construction with insulation gives a benefit of about 2%. Glazing ratio has little impact though low glazing ratio is the best by a small amount. North and South orientations slightly better than East and West. Ground floor location is better than first floor by about 2%. Medium air change rate is best by a small amount. The overall range of values for Chongqing is quite modest and the comfort level is low, however this might be expected for a city known as one of the 'three furnaces of China' because of the summer heat.

Nanning, Guangxi: average discomfort hours 73.6% (range 65.8%-78.9%). Lightweight construction with insulation gives a benefit of about 6%. Glazing ratio has little impact. Main orientation makes little difference. Ground floor location has similar outcomes to the first floor. Low and medium air change rate is best by about 2.5%. Again the range is modest because conditions are generally warm and humid.

Guiyang, Guizhou: average discomfort hours 69.3% (range 58.6%-75.4%). Lightweight construction with insulation gives a benefit of about 5%. Glazing ratio has little impact though low glazing ratio is the best by about 1%. North and South orientations slightly better than East and West by about 1.5%. Ground floor location is better than first floor by about 5%. Medium air change rate is best by about 1%. The range of values is a little higher in this city which does experience a wider range of climate.

Chengdu, Sichuan: average discomfort hours 71.8% (range 64.6%-76.9%). Lightweight construction with insulation gives a benefit of about 6%. Glazing ratio has little impact though. Main orientation has little impact. Ground floor location is better than first floor by about 2%. Medium air change rate is best by a small amount. Another city with only a rather modest range of climatic variation.

Kunming, Yunnan: average discomfort hours 57.3% (range 35.4%-71.6%). Lightweight construction with insulation gives a benefit of about 10%. Glazing ratio has little impact. South orientation is slightly better than others by about 1.5%. Ground floor location is better than first floor for two wall constructions, but not the best design of lightweight with insulation. Low air change rate is best by about 1.5%. Kunming offers the least uncomfortable conditions which is perhaps unsurprising for the city of 'eternal spring'; the worst overheating potential is ameliorated by the altitude of the location.

Though an initial reaction would be that the potential changes for a number of locations is modest, in every case, and bearing in mind the parametric variations were limited, there is potential to improve operation by reducing the percentage of discomfort hours by a significant amount.

7. Summary and conclusions

This paper has focused attention on the provision of comfort in dwellings of SW China. This region and its buildings are important because they represent a number of features of redevelopment in a sub-area of the country which is often neglected when thinking about environmental design and comfort. The fact that the population and number of dwellings affected is larger than most countries means the impacts can be very significant. Research is ongoing into this area and further outcomes will result.

The bullet point list below summarise the key findings:

- Rural China offers a large opportunity to improve energy efficient design both because of the type of settlements and because of the sheer number of inhabitants;
- there is an under-optimised opportunity to produce better climate sensitive housing;
- one of the key barriers to progress is lack of guidance and communication to stakeholders;
- design and construction professionals need better guidance and improved understanding of thermal comfort issues in dwelling design;
- local inhabitants have capacity to be involved and take more control to achieve comfort if they are better informed;
- rural buildings are neither built nor used like urban counterparts, yet occupants aspire to urban equivalents because of impressions of what modern design should be;
- there is need to understand the specific location for development and in particular the climate – this is because relatively short distances can produce significant swings in the optimum design techniques;
- the results from the analyses suggest alternative forms of construction should be considered, including greater use of insulation in the envelope;
- controlled natural ventilation can make a useful contribution to the achievement of comfort;
- the role of internal heat gains in offsetting impacts from cooler conditions should be better understood;
- the need for many of these actions is now, both because of the changing climate and also in SW China because of the speed that redevelopment takes place.

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Appendix A:

Appendix: Information box
Input data for EnergyPlus simulations

The main characteristics/features of the simple building were:

- Key external dimensions: width: 7.8 m; depth: 8.1 m; 2 floors—floor to floor height 3 m; intermediate floor 0.1 m concrete;
- Double wood door to front elevation 2.4 m high, 1.4 m wide;
- Walls: main component thickness (without insulation or cavity) = 0.24 m;
- Windows: 1.5 m in height; bottom of window 0.9 m above floor; glazing only to front (main) façade and rear façade; variations in window size accommodated by changing the width;
- 2 occupants per floor (1 met activity level); clothing insulation value: 0.7 clo; no other heat gains apart from occupants were incorporated due to the level of complexity.

A series of parametric alternatives were then chosen for other building features:

- Four principal orientations: north, east, south, west;
- Three glazing options (all single glazed):
  low glazing ratio: front window to wall area ratio (WWR) = 0.2, rear WWR = 0.15;
  medium glazing ratio: front WWR = 0.35, rear = 0.25;
  high glazing ratio: front WWR = 0.5, rear WWR = 0.35.
- Three variations in construction with different thermal impacts:
  Heavyweight: load bearing concrete frame with dense brick infill walls plus 0.015m internal plasterboard finish; concrete roof structure 0.1m thick, concrete floor 0.1m.thick;
  Lightweight: lightweight concrete block walls plus 0.015m internal plasterboard; concrete roof structure 0.1m thick, concrete floor 0.1m. thick;
  Lightweight with Insulation: lightweight concrete block walls with internal insulation of 0.1m; plus 0.015m internal plasterboard; concrete roof structure 0.1m with 0.1m internal insulation, concrete floor 0.1m (no insulation).
- Ventilation rates: 0.25/0.5/1.0 air changes per hour.

Table 2: Improvement in comfort hours experienced (expressed as a percentage of total hours in the year)

		Comfort	Sun shading	High thermal mass	High thermal mass + night Flush vent.	Direct Evaporative Cooling	Two-stage Evaporative Cooling	Natural ventilation	Fan-forced ventilation	Internal heat gain	Passive Solar Direct Gain Low Mass	Passive Solar Direct Gain High Mass	Wind Protection	Humidification Only	Dehumidification Only	Cooling	Heating	**Selected design strategies (total for passive or all techniques)**	
	Comfort model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**Passive**	**All**
Shapingba	PMV	5.2	7.5	0.4	0.5	0.4	0.5	0.3	0.3	22.4	1.1	1.6	0	0	22.9	18.3	30.1	**28.6**	**99.8**
(Chongqing)	Adaptive (+PMV)	5.2	7.5	0.4	0.5	0.4	0.5	**22.1**	0.3	22.4	1.1	0.9	0	0	22.9	10.8	30.3	**47.2**	**99.9**
Nanning	PMV	4.8	12.7	0.2	0.2	0.2	0.3	0.3	0.3	22.3	1.9	4	0	0	27.5	33.2	10.5	**28.8**	**99.8**
(Guangxi)	Adaptive(+PMV)	4.8	12.7	0.2	0.2	0.2	0.3	**37.3**	0.3	22.3	1.9	2.3	0	0	27.5	15.9	11.3	**62.1**	**99.9**
Guiyang	PMV	7.8	8.2	0.4	0.4	0.4	0.4	0.4	0.3	27.3	2.2	4.8	0	0	21.7	5.3	35.4	**37.9**	**100**
(Guizhou)	Adaptive(+PMV)	7.8	8.2	0.4	0.4	0.4	0.4	**18.3**	0.3	27.3	2.2	3	0	0	21.7	3.5	36.5	**50.0**	**100**
Chengdu	PMV	5.3	10	0.7	0.7	0.7	0.7	0.6	0.5	21.5	2.4	3.3	0	0	26.9	8.9	34.9	**29.6**	**100**
(Sichuan)	Adaptive(+PMV)	5.3	10	0.7	0.7	0.7	0.7	**20.1**	0.5	21.5	2.4	1.1	0	0	26.9	5.3	35.8	**45.1**	**100**
Kunming	PMV	17.3	4.3	0.3	0.3	0.3	0.3	0.3	0.3	47.4	9.6	18.1	0	0	5.5	0.1	21.4	**73.4**	**100**
(Yunnan)	Adaptive(+PMV)	17.3	4.3	0.3	0.3	0.3	0.3	**14.4**	0.3	47.4	9.6	10.3	0	0	5.5	0.1	26.3	**70.7**	**100**

Table 3: Discomfort Hours for City of Chengdu, Sichuan with PMV>+1 or PMV<-1 (percentage of hours in the year)

Discomfort hours summary		Chengdu, Sichuan																	
		Heavy walls						**Lightweight walls**						**Lightweight insulated walls**					
		0.25 ACH		**0.5 ACH**		**1 ACH**		**0.25 ACH**		**0.5 ACH**		**1 ACH**		**0.25 ACH**		**0.5 ACH**		**1 ACH**	
		Ground	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**
Low glazing	**South**	71.5%	74.1%	70.9%	73.9%	73.4%	76.0%	71.2%	74.2%	71.0%	74.1%	72.7%	75.9%	65.1%	66.5%	64.6%	65.3%	65.8%	67.9%
	North	71.4%	74.2%	71.1%	74.0%	73.4%	76.0%	71.3%	74.3%	71.1%	74.2%	72.8%	76.0%	65.3%	66.7%	64.7%	65.7%	65.9%	68.1%
	East	71.8%	74.4%	71.4%	74.2%	73.6%	76.2%	71.8%	74.7%	71.4%	74.3%	73.2%	76.4%	66.2%	67.7%	65.6%	66.8%	67.4%	69.3%
	West	71.9%	74.3%	71.2%	74.2%	73.6%	76.2%	71.7%	74.7%	71.4%	74.5%	73.2%	76.4%	66.3%	67.9%	65.6%	66.9%	67.3%	69.4%
Medium glazing	**South**	71.7%	74.1%	71.0%	74.0%	73.3%	76.0%	71.3%	74.3%	71.0%	74.1%	72.8%	76.0%	65.5%	67.2%	65.1%	66.4%	66.4%	68.1%
	North	71.8%	74.3%	71.1%	74.1%	73.4%	76.1%	71.4%	74.4%	71.1%	74.2%	72.9%	76.0%	65.8%	67.5%	65.5%	66.7%	66.8%	68.6%
	East	72.1%	74.3%	71.6%	74.3%	73.8%	76.4%	71.9%	74.9%	71.6%	74.7%	73.5%	76.6%	66.9%	68.8%	66.4%	68.0%	68.5%	70.1%
	West	72.2%	74.5%	71.6%	74.4%	73.7%	76.4%	71.9%	75.1%	71.6%	74.7%	73.4%	76.6%	67.2%	69.3%	66.5%	68.4%	68.5%	70.3%
High glazing	**South**	71.5%	74.0%	71.0%	73.9%	73.4%	76.1%	70.8%	74.4%	70.8%	74.1%	72.7%	75.9%	66.2%	67.8%	65.5%	67.4%	67.2%	69.0%
	North	71.7%	74.1%	70.9%	74.0%	73.5%	76.2%	71.0%	74.4%	71.0%	74.2%	72.8%	76.1%	66.4%	68.2%	65.8%	67.7%	67.6%	69.4%
	East	72.2%	74.5%	71.7%	74.5%	73.8%	76.5%	71.8%	75.1%	71.6%	74.7%	73.6%	76.7%	67.8%	70.0%	67.2%	69.4%	69.5%	71.2%
	West	72.2%	74.5%	71.7%	74.5%	73.8%	76.5%	71.9%	75.2%	71.6%	74.9%	73.6%	76.9%	68.1%	70.3%	67.4%	69.8%	69.6%	71.7%

Table 4: Discomfort Hours for City of Guiyang, Guizhou with PMV>+1 or PMV<-1 (percentage of hours in the year)

Discomfort hours summary		Guiyang, Guizhou																	
		Heavy walls						**Lightweight walls**						**Lightweight insulated walls**					
		0.25 ACH		**0.5 ACH**		**1 ACH**		**0.25 ACH**		**0.5 ACH**		**1 ACH**		**0.25 ACH**		**0.5 ACH**		**1 ACH**	
		Ground	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**
Low glazing	**South**	67.8%	72.8%	66.4%	71.9%	68.0%	73.5%	67.5%	72.6%	66.7%	72.0%	69.4%	73.9%	59.5%	64.5%	58.6%	63.3%	62.6%	64.4%
	North	67.9%	73.0%	66.4%	71.9%	68.0%	73.6%	67.7%	72.8%	66.7%	72.1%	69.5%	74.0%	59.7%	65.1%	58.8%	64.0%	62.7%	64.6%
	East	68.4%	73.5%	67.1%	72.4%	68.4%	73.9%	68.4%	73.2%	67.5%	72.6%	69.9%	74.4%	62.9%	67.5%	61.5%	66.6%	64.1%	67.7%
	West	68.6%	73.6%	67.4%	72.6%	68.6%	74.0%	68.5%	73.4%	67.6%	72.7%	70.1%	74.6%	63.9%	68.0%	62.4%	67.4%	64.4%	68.7%
Medium glazing	**South**	67.9%	73.0%	66.8%	72.1%	68.2%	73.5%	68.0%	72.8%	67.0%	72.2%	69.6%	74.0%	61.8%	66.3%	60.6%	65.0%	63.3%	66.2%
	North	68.1%	73.1%	67.0%	72.3%	68.3%	73.7%	68.1%	72.9%	67.2%	72.5%	69.7%	74.2%	62.4%	67.0%	61.0%	65.9%	63.5%	67.0%
	East	69.0%	73.9%	67.7%	72.8%	68.9%	74.1%	68.8%	73.6%	67.9%	72.9%	70.3%	74.8%	65.8%	69.7%	64.1%	68.8%	65.4%	70.4%
	West	69.4%	74.0%	67.9%	73.0%	69.3%	74.4%	69.1%	73.9%	68.1%	73.2%	70.7%	74.9%	66.8%	70.6%	65.3%	69.9%	66.2%	71.8%
High glazing	**South**	68.3%	73.1%	66.9%	72.3%	68.5%	73.7%	68.1%	72.9%	67.2%	72.3%	69.7%	74.2%	63.8%	68.2%	62.1%	67.1%	64.4%	67.7%
	North	68.4%	73.2%	67.0%	72.5%	68.5%	73.8%	68.3%	73.1%	67.4%	72.4%	69.9%	74.4%	64.6%	68.7%	62.8%	67.6%	64.8%	68.5%
	East	69.8%	74.3%	68.3%	73.3%	69.5%	74.6%	69.6%	73.9%	68.6%	73.3%	70.8%	75.1%	68.0%	71.7%	66.6%	70.9%	67.3%	72.6%
	West	70.1%	74.6%	68.6%	73.6%	70.0%	74.9%	69.8%	74.5%	68.8%	73.6%	71.1%	75.4%	68.8%	72.4%	67.7%	71.8%	67.8%	73.9%

Table 5: Discomfort Hours for City of Kunming, Yunnan with PMV>+1 or PMV<-1 (percentage of hours in the year)

Discomfort hours summary				**Kunming, Yunnan**															
		Heavy walls						**Lightweight walls**						**Lightweight insulated walls**					
		0.25 ACH		**0.5 ACH**		**1 ACH**		**0.25 ACH**		**0.5 ACH**		**1 ACH**		**0.25 ACH**		**0.5 ACH**		**1 ACH**	
		Ground	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**
Low glazing	**South**	52.0%	58.7%	55.1%	59.2%	68.7%	64.5%	54.2%	62.0%	56.8%	62.7%	70.2%	68.8%	46.5%	38.2%	51.3%	41.2%	70.5%	52.4%
	North	52.4%	58.9%	55.4%	59.5%	69.0%	64.8%	54.6%	62.5%	57.3%	63.2%	70.6%	69.0%	47.9%	41.0%	52.6%	43.4%	71.6%	53.9%
	East	51.9%	59.4%	54.6%	59.9%	67.7%	65.1%	54.6%	63.0%	56.8%	63.5%	69.2%	69.0%	45.5%	43.4%	49.9%	43.9%	67.0%	51.0%
	West	52.0%	59.6%	54.5%	60.0%	67.2%	65.1%	54.8%	63.3%	56.8%	63.6%	68.9%	69.2%	44.5%	44.4%	49.0%	44.7%	65.3%	51.0%
Medium glazing	**South**	51.3%	58.6%	54.0%	59.2%	67.2%	64.4%	53.5%	61.8%	55.9%	62.4%	68.9%	68.5%	44.5%	35.4%	49.2%	37.8%	66.9%	48.7%
	North	52.0%	59.1%	54.6%	59.6%	67.8%	64.9%	54.2%	62.7%	56.7%	63.0%	69.5%	69.1%	47.0%	41.5%	51.2%	43.1%	68.7%	52.2%
	East	51.5%	59.9%	53.9%	60.1%	66.2%	65.1%	54.6%	63.6%	56.4%	63.9%	68.0%	69.1%	44.6%	47.9%	48.1%	47.1%	63.1%	51.7%
	West	51.8%	60.3%	53.9%	60.2%	65.5%	65.4%	55.0%	63.7%	56.6%	63.9%	67.8%	69.2%	44.1%	48.9%	47.2%	48.5%	61.1%	52.3%
High glazing	**South**	50.7%	58.8%	53.5%	59.2%	65.9%	64.4%	52.9%	61.5%	55.3%	62.2%	67.8%	68.0%	41.4%	37.6%	46.8%	38.3%	64.2%	46.4%
	North	51.4%	59.4%	54.1%	59.8%	66.6%	64.9%	54.0%	62.7%	56.2%	63.2%	68.5%	68.9%	45.9%	42.7%	49.9%	43.4%	65.9%	51.3%
	East	51.7%	60.6%	53.6%	60.7%	64.8%	65.2%	55.0%	63.8%	56.4%	64.2%	67.2%	69.2%	45.3%	52.3%	47.7%	51.2%	60.2%	54.2%
	West	52.0%	61.1%	53.9%	61.3%	64.4%	65.6%	55.2%	63.8%	56.7%	64.3%	67.0%	69.3%	45.8%	53.7%	47.5%	52.5%	59.2%	55.2%

Table 6: Discomfort Hours for City of Nanning, Guangxi with PMV>+1 or PMV<-1 (percentage of hours in the year)

Discomfort hours summary				**Nanning, Guangxi**															
		Heavy walls						**Lightweight walls**						**Lightweight insulated walls**					
		0.25 ACH		**0.5 ACH**		**1 ACH**		**0.25 ACH**		**0.5 ACH**		**1 ACH**		**0.25 ACH**		**0.5 ACH**		**1 ACH**	
		Ground	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**	**Ground**	**1st floor**
Low glazing	**South**	73.5%	76.1%	73.5%	75.9%	77.3%	78.4%	73.4%	76.0%	73.4%	75.8%	76.4%	77.0%	65.8%	66.8%	66.6%	66.4%	71.1%	69.5%
	North	73.6%	76.2%	73.6%	76.1%	77.5%	78.5%	73.6%	76.1%	73.7%	75.8%	76.5%	77.2%	66.6%	66.9%	67.4%	66.8%	71.6%	70.1%
	East	74.0%	76.5%	74.0%	76.5%	77.8%	78.8%	74.1%	76.3%	74.1%	76.0%	77.0%	77.7%	67.7%	68.0%	68.4%	68.0%	72.7%	71.7%
	West	73.9%	76.4%	74.1%	76.4%	77.7%	78.7%	74.1%	76.3%	74.1%	76.2%	78.3%	78.9%	67.8%	68.1%	68.5%	68.2%	72.8%	71.7%
Medium glazing	**South**	73.1%	75.9%	73.1%	75.7%	77.1%	78.2%	73.0%	76.0%	73.1%	75.8%	76.0%	77.0%	66.0%	68.4%	66.5%	67.5%	70.2%	69.5%
	North	73.3%	76.1%	73.3%	75.9%	77.3%	78.5%	73.3%	76.1%	73.5%	75.8%	76.2%	77.0%	66.6%	68.1%	67.2%	67.6%	71.2%	70.4%
	East	73.9%	76.4%	73.8%	76.2%	77.7%	78.8%	73.8%	76.5%	73.9%	76.3%	76.9%	77.8%	67.9%	69.2%	68.3%	68.9%	72.4%	71.8%
	West	73.9%	76.4%	73.8%	76.3%	77.8%	78.8%	73.9%	76.6%	73.9%	76.3%	77.0%	77.8%	68.2%	69.6%	68.6%	69.2%	72.5%	72.0%
High glazing	**South**	72.7%	75.7%	72.8%	75.7%	76.8%	77.9%	72.8%	76.2%	72.9%	75.8%	75.8%	77.0%	67.3%	70.0%	67.0%	69.1%	70.3%	70.3%
	North	73.1%	76.0%	73.1%	75.9%	77.0%	78.3%	73.0%	76.3%	73.2%	75.9%	76.2%	77.2%	67.4%	69.2%	67.4%	68.7%	71.0%	70.7%
	East	73.8%	76.3%	73.8%	76.3%	77.8%	78.7%	73.7%	76.9%	73.7%	76.5%	77.0%	78.0%	68.7%	70.5%	68.8%	70.1%	72.7%	72.6%
	West	73.8%	76.4%	73.9%	76.3%	77.8%	78.7%	73.8%	76.9%	73.9%	76.6%	77.0%	78.0%	69.1%	70.9%	69.1%	70.4%	72.8%	72.6%

Table 7: Discomfort Hours for City of Chongqing (Shapingba) with PMV>+1 or PMV<-1 (percentage of hours in the year)

Discomfort hours summary		Shapingba, Chongqing																	
		Heavy walls						Lightweight walls						Lightweight insulated walls					
		0.25 ACH		0.5 ACH		1 ACH		0.25 ACH		0.5 ACH		1 ACH		0.25 ACH		0.5 ACH		1 ACH	
		Ground	1st floor	Ground	1st floor	Ground	1st floor	Ground	1st floor	Ground	1st floor	Ground	1st floor	Ground	1st floor	Ground	1st floor	Ground	1st floor
Low glazing	South	75.5%	77.1%	74.8%	76.7%	75.1%	77.9%	75.0%	77.0%	74.4%	76.5%	75.0%	77.8%	73.2%	74.4%	71.9%	73.6%	71.4%	73.6%
	North	75.4%	77.1%	74.8%	76.7%	75.0%	77.9%	75.0%	77.0%	74.4%	76.5%	75.0%	77.9%	73.3%	74.6%	71.8%	73.7%	71.3%	73.9%
	East	75.6%	77.3%	75.0%	76.8%	75.4%	78.1%	75.4%	77.2%	74.7%	76.8%	75.3%	78.2%	74.3%	75.4%	72.8%	74.6%	72.5%	74.7%
	West	75.6%	77.4%	75.0%	76.9%	75.4%	78.2%	75.3%	77.3%	74.7%	76.9%	75.2%	78.3%	74.4%	75.6%	72.9%	74.8%	72.6%	74.7%
Medium glazing	South	75.6%	77.3%	75.0%	76.8%	75.3%	78.0%	75.0%	77.1%	74.4%	76.7%	75.1%	78.0%	74.0%	75.2%	72.7%	74.2%	72.5%	74.4%
	North	75.6%	77.3%	75.0%	76.9%	75.2%	78.0%	75.1%	77.1%	74.4%	76.6%	75.1%	78.0%	74.3%	75.4%	72.9%	74.3%	72.6%	74.5%
	East	75.9%	77.6%	75.2%	77.3%	75.7%	78.3%	75.5%	77.5%	74.9%	77.0%	75.5%	78.4%	75.1%	76.6%	73.9%	75.7%	73.8%	75.6%
	West	75.9%	77.6%	75.3%	77.3%	75.7%	78.3%	75.5%	77.6%	74.9%	77.0%	75.5%	78.5%	75.2%	77.0%	74.0%	76.0%	73.8%	76.0%
High glazing	South	75.4%	77.5%	75.0%	76.9%	75.4%	77.9%	75.1%	77.3%	74.5%	76.7%	75.0%	78.2%	74.6%	76.2%	73.4%	75.2%	73.3%	75.2%
	North	75.6%	77.5%	75.1%	76.8%	75.4%	78.1%	75.2%	77.3%	74.6%	76.8%	75.0%	78.2%	74.8%	76.4%	73.6%	75.3%	73.4%	75.3%
	East	76.0%	77.8%	75.4%	77.3%	75.9%	78.3%	75.7%	77.8%	74.9%	77.4%	75.5%	78.7%	75.9%	77.7%	74.5%	76.7%	74.5%	76.8%
	West	75.9%	78.0%	75.4%	77.5%	75.9%	78.5%	75.9%	78.0%	75.2%	77.5%	75.7%	78.9%	76.2%	78.2%	74.7%	77.0%	74.8%	77.2%